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MOHAWK LAKE BEDS

BY

HENRY WARD TURNER

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GENERAL REMARKS.

The facts presented in this paper were gathered in the course of my regular field-work as assistant of Mr. G. F. Becker, geologist in charge of the California Division of the United States Geological Survey.

For assistance in connection with the publication I am indebted to Mr. Becker, to Mr. J. S. Diller, and to Mr. W J McGee.

The memoirs and papers referred to will be found in a list at the end.

On the accompanying map, Plate No. 4, the areas indicated as Pre-tertiary include all of the rocks known ordinarily

as bed-rock to the miner, on which the late Cretaceous and Tertiary rocks rest unconformably everywhere in the Sierra Nevada. These rocks about Mohawk Valley are granite, diabase, porphyrites, and clastic rocks of Paleozoic or early Mesozoic age.

Mohawk Valley is in Plumas county, California, on the eastern slope of the Sierra Nevada. Its general location may be seen in Figure 1. The geological map of Mohawk Valley and vicinity, Plate No. 4, covers the area included in the rectangle in Figure 1.

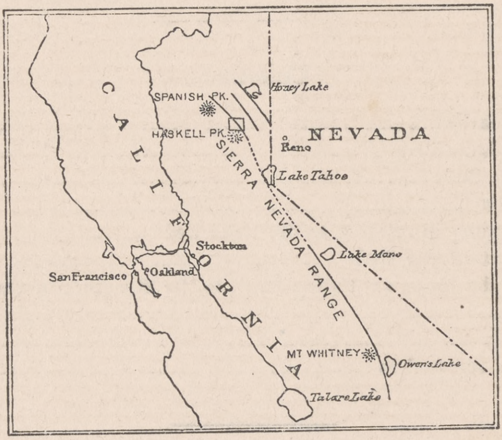
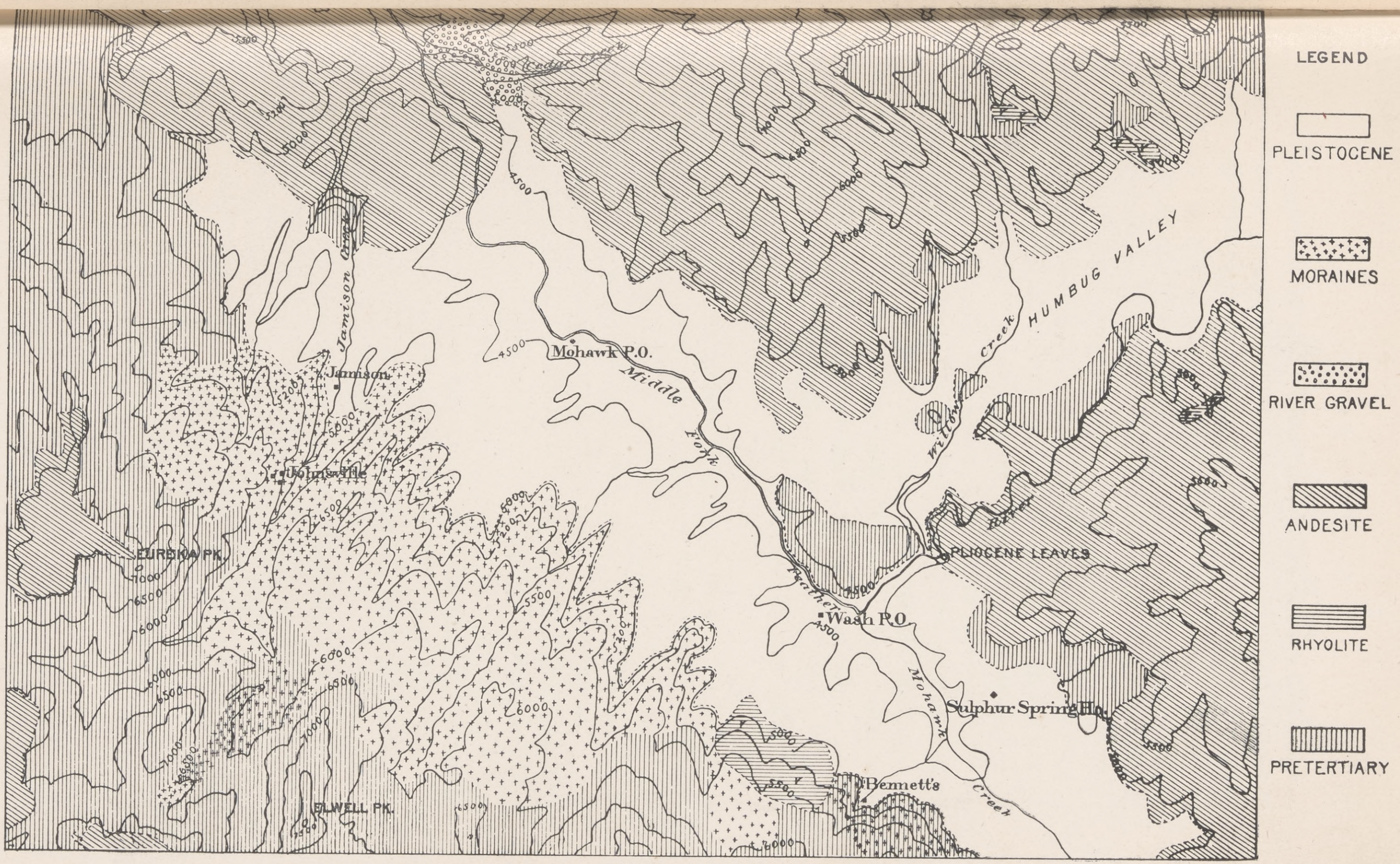


FIG. 1—Outline sketch of central California.

That Mohawk Valley was once the bed of a lake is evident from the deposits of fine stratified material underlying it and from the terraces about it. The elevation of the lower parts of the valley, now occupied by farms, is about 4,500 feet and that of the highest terraces something more than 5,000 feet. There was thus at one time a depth of water of more than 500 feet. We will first consider the certainly Pleistocene deposits.

Pleistocene Lake Beds.

The middle fork of the Feather River now flows through the valley, the former lake having been merely a widening



GEOLOGICAL MAP OF MOHAWK VALLEY AND VICINITY

SCALE

0 1 2 3 MILES

and deepening of this stream. If we seek for the cause of the former existence of the lake it will be found to be connected with volcanic outflows that occurred about the close of the Pliocene or in early Pleistocene time.

Judging from the present contours of the surface of the bed-rock formations (granite and the auriferous slate series), the middle fork of the Feather River at the present time follows approximately an older drainage system, which existed before the volcanic outflows, though perhaps not for a great length of time. These outflows, largely andesitic breccia and tufa, filled up the cañon that then existed, and the waters thus dammed back formed the Pleistocene lake here treated of. Since that time the river has cut through the barrier, and the lake has been drained. For three miles north of the Mohawk lake beds the Feather River at the present time flows through a cañon, the walls and bottom of which are composed entirely of andesitic and some later lavas.

Pebbles of andesite and of rhyolite abound in the lake beds, and, to the north and east of Mohawk Valley, thin patches of lake deposit may be seen at many points to rest upon the andesite. It is therefore certain that the lake attained its maximum development after the andesitic eruptions.

The lake at its highest level not only filled Mohawk Valley, but extended east into Humbug Valley, having a surface of, approximately, thirty-five square miles. The deposits at the highest stage were largely rather fine material, andesitic and morainal detritus, which has since been much eroded, particularly on the east side of Mohawk Valley, where well-defined terraces are not to be found.

But in the northwestern portion of the lake area, at an altitude of about 5,000 feet, the terraces are well preserved. The road from Mohawk Post Office to the mining town of Johnsville passes over some of these terraces. They are now heavily wooded. Exposures of them at various points show them to be composed of loose sand and gravel distinctly stratified, the bedding being approximately horizontal.

Forming a set of terraces about 4,500 feet high about Mohawk Valley and well exposed along the Feather River where it enters the valley from the east, and by the public road just south of Wash Post Office, are beds of coarse gravel and sand containing some pebbles of late olivine basalt, a lava of much later age than the andesite. These beds appear to be the latest of the lake deposits. Lying usually somewhat below the 4,500 foot contour is the alluvium, which will not be considered here as part of the lake beds. The alluvium is of very recent origin.

Earlier Lake Beds.

Underlying the coarser deposits, previously described, is an older series of beds not anywhere found, so far as I know, at a much greater elevation than 4,600 feet. These older beds are usually whitish in color and composed largely of sand and clay, with layers of carbonaceous shale. Since there is some doubt about the age of the beds, exposed at different points, some of them will be described separately.

About one-fourth of a mile down-stream from Mohawk Post Office, on the west bank of the Feather River, and forming also the bed of the river, are beds, largely clay and sand, with a good deal of carbonaceous shale. Distinctly and unconformably overlying the fine material, which is horizontally stratified, is a later gravelly series, with some sand and clay. Vertically above the line of contact in the later material are some angular blocks of carbonaceous shale, only a few feet from the carbonaceous layer from which they came. There must have elapsed between the formation of the earlier fine and the later gravelly deposits sufficient time for some erosion and consolidation of the earlier beds to have taken place. It is also evident that the earlier deposition took place in comparatively still and deep water, while the later gravelly beds could only have been deposited in water moving with some rapidity. The entire exposure is about sixty feet high.

The later beds are correlated with the gravels forming the 4,500 foot terraces previously described.

On Grey Eagle Creek, about one and a half miles nearly south of Mohawk Post Office, at an elevation of about 4,600 feet, is another exposure of beds very similar to the older beds just described, with much clay, sand, and carbonaceous shale.

In addition there was observed a fine white layer, a few inches in thickness, composed almost entirely of volcanic glass in angular fragments with fluted forms, very similar to some material described as volcanic dust by Mr. G. P. Merrill (XV). The most reasonable explanation of the homogeneity of the volcanic layer is to suppose that it was thrown out in its present fine condition, and falling in the water, was deposited as we now find it. It might also be supposed that it was eroded from an area of volcanic ash near by and re-deposited on the lake bottom. In either case it marks approximately the age of the eruption, since, if the result of the erosion, it could hardly fail, after a considerable period had elapsed, to be much mixed with other detrital material. The angular character of the dust is against its having undergone much transportation, though fine thin glass would doubtless be not greatly rounded, but rather broken into finer angular particles. The material presents all the appearance of being rhyolitic glass. This is further substantiated by a silica determination made by Dr. W. H. Melville, of the United States Geological Survey. He found the fine white powder from Grey Eagle Creek to contain 70.64 per cent. of silica, while a rhyolite from near Mohawk Valley contains 71.14 per cent.

Now the rhyolites of the Sierra Nevada in general underlie the andesites. Indeed, in some places, there is proof that they were eroded somewhat before the andesitic eruptions.

Evidence gathered by Mr. Waldemar Lindgren and myself at a great many localities in the Sierra Nevada all points to the rhyolites being older than, at least, the hornblende-andesites which form the great bulk of the andesitic eruptions.

It is therefore likely that the Grey Eagle Creek and Mohawk Post Office beds belong to a lake that existed before the

Pleistocene lake, formed by the damming back of waters by the later andesite. Further evidence on this point will be presented in a succeeding paragraph.

Southeast of the Sulphur Spring House, in the southern part of Mohawk Valley, is some sandstone sufficiently consolidated to be used for chimneys. This hardening of the material has probably been brought about by the cementing action of the waters of the adjacent springs. Some of the sandstone shows plant impressions. The sandstone is bedded nearly horizontally. Just east of the sulphur springs there is a disturbance in the lake beds, the dip being southwest 22°.

About one-fourth mile north of the Sulphur Spring House, on the north bank of a little stream, is an exposure of lake beds, which dip westerly about 13°. The material is rather fine detritus. A microscopical examination of a whitish layer showed sand grains, fragments of volcanic glass, green hornblende, biotite, apatite, and black opaque grains, presumably magnetite. The volcanic glass appears to be rhyolitic; the sand grains, hornblende, biotite, and apatite are probably from granite.

The narrow area of river gravel to the north of the lake beds and directly connecting with them has at first sight the appearance of being the bed of a former outlet of the lake, but as some of this gravel lies at an elevation of 5,500 feet this does not seem likely. There are indications of local disturbances here, in the form of little benches, such as are to be found where land slides have taken place. It is probable that the low position of part of this gravel just to the north of the mouth of Cedar Creek is due to subsidence by a land slide. This river gravel seems, on the map, Plate No. 4, to rest on andesite, but this is not the case, the rock underlying the gravel being of the auriferous slate series.

Pliocene Beds.

There are some beds exposed along the middle fork of the Feather River, a little to the east of Mohawk Valley, on the ranch of Abel Jackson. These beds consist of sandstone

with a little lignite and carbonaceous shale, and at one point where some sulphur springs issue forth the very fine-grained layers contain numerous well-preserved leaves, mostly of deciduous trees. Professor Ward has made a preliminary examination of these leaves and identifies two forms as *Quercus distincta* and *Liquidambar Californica.** Some of the leaves are probably new. In the summer of 1890 I obtained here impressions of a bunch of pine leaves and of a winged maple seed. Professor Ward considers the plant remains to indicate that the beds are about of the same horizon as the auriferous gravels, apparently meaning the later and more abundant gravels which occur in considerable amount on the western slope of the Sierra Nevada, and which seem to be but little older than the volcanic material that usually covers them. These later and more abundant gravels are generally considered of Pliocene age. The Sierra Nevada has undoubtedly been a land mass since, at least, early Cretaceous time (since the post-Mariposa upheaval). It is therefore extremely probable that some of the river gravels of the Sierra were deposited by streams that flowed in early Tertiary or even late Cretaceous times.

For positive evidence of there being older river channels, which in some cases are intersected by later channels, the reader is referred to R. E. Browne's paper on "Ancient River Beds" (II), which will be again mentioned further on. The beds above described containing the fossil leaves have a westerly dip varying from 5° to 30° and are distinctly overlaid by andesitic breccia.

I am inclined to correlate the horizontal beds containing carbonaceous shale at Mohawk Post Office and Grey Eagle Creek, previously described, with the certainly pre-andesitic beds, but I have been unable to find any barrier that existed before the time of the andesitic eruptions that could have

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* In his "Report on the Fossil Plants of the Auriferous Gravels of the Sierra Nevada," Memoirs Museum Comp. Zool., Vol. VI, No. 2, Professor Lesquereux describes these two species from Chalk Bluffs, Nevada county, referring the beds to the Pliocene.

retained sufficient water to deposit beds of the character described. Moreover, the Mohawk Post Office beds seem to continue north and abut against the andesitic barrier. The Grey Eagle Creek beds have an approximate elevation of 4,600 feet, at least 100 feet higher than at Mohawk Post Office, to which they are so similar. It is possible the first-mentioned beds have attained their present position through differential elevation or subsidence, though as the beds at both exposures are approximately horizontal this does not seem likely.

The beds from which the leaves came may simply record a quiet stage of the former Feather River. The river is probably now, in fact, depositing similar material in the numerous nearly quiet stretches between Mohawk and Sierra Valleys.

Glacial Moraines in Relation to the Lake Beds.

All about Johnsville are enormous accumulations of morainal material. Over an area of fifteen square miles none of the underlying formations are exposed, so deep is the morainal detritus. This is largely made up of diabase and quartz, porphyrite boulders, and subangular fragments from the extensive areas of these rocks in the high ridge to the west and southwest, the east and north slopes of which formed the nevé fields of the glaciers. Mounts Elwell, Bunker Hill, and Eureka Peak are prominent northward-trending spurs of this high ridge, and between these spurs the glaciers were nourished.

The moraines merge into the lake deposits, and opposite Jamison, on the east side of Jamison Creek, there is an exposure of the moraine material at the point where the highest lake terrace begins. The underlying coarse gravel and subangular material are roughly stratified. This would suggest that the maximum period of the glaciers and that of the Pleistocene lake occurred at the same time, for if the water had terraced the moraines subsequent to their deposition it seems probable that there would be no internal stratification, but only a surface leveling of the material.

Some of the moraine material poorly exposed on the opposite (west) side of Jamison Creek at the same elevation (about 5,000 feet) shows less evidence of stratification.

In the bed of Jamison Creek just below the bridge at Jamison, a shaft was sunk some years ago to the depth of 270 feet, all in gravel. This shaft is still to be seen. There must therefore be an enormous amount of detrital material here.

The town of Johnsville rests on a terrace-like embankment, the upper part of which shows some stratification. A similar though narrower terrace exists on the east side of Jamison Creek opposite Johnsville. The stratified material could not have been deposited when the cañon was filled with ice and may have been formed by a slight damming up of the waters of the creek after the retreat of the glacier.

On the west side of Mohawk Valley, at an elevation of about 5,000 feet, is Bennett's hydraulic mine. The upper part of the material washed is clay with scratched boulders, traces of a rough stratification being visible, which may have been due to water from melting ice.

A little lower down, however, the material is more arenaceous, shows bedding plainly, and is traversed by normal faults at two points, the down-throw of each being toward the valley at an angle of perhaps 30° from verticality, and the throw in each case being about one foot. This lower material is thought to represent the highest terrace of Mohawk Lake. The inclination of the stratification is toward the valley or easterly, and this may be explained by the steepness of the slope on which it was deposited rather than by any subsequent disturbance. The well-worn gravel at Bennett's hydraulic mine is thought to have come from an old river channel that formerly existed higher up on the slope, remnants of which are still to be seen.

There are frequent large boulders of diabase on the lake beds near the north end of the area, where the outlet of the lake presumably was, and these may have been brought to their present position by floating ice. There is no diabase

in place exposed near them, while the glacial moraines near Johnsville are largely of diabase débris.

Mr. I. C. Russell, in his paper on the Quaternary basin of Lake Mono (XVI), states that the inside as well as the ends of some of the lateral moraines at Lake Mono are terraced, showing that the highest stage of the lake either followed or continued after the retreat of the glaciers, for the inside of the lateral moraines must have been filled with ice at the period of maximum glaciation. Mr. Russell suggests that the melting of the glaciers produced the maximum stage of the lake.

Professor Le Conte (X) considers that the absence of terminal moraines can be accounted for on the hypothesis that the maximum stage of the glacier and that of the ice coincided, for then the loose material that would have formed a terminal moraine would be carried away by floating ice. Professor Le Conte accounts for the presence of large boulders at certain points about Lake Mono by supposing them to have been transported by icebergs.

When at Lake Mono, in 1889, in company with Mr. G. F. Becker, it was observed that a rough stratification existed in the end of the Lundy moraine, the material being well exposed by mining operations; and in the opinion of Mr. Becker this would show that the end of the glacier extended into the water, the morainal material being roughly stratified as it dropped off.

The true explanation may be that the high stage of the water was both contemporaneous with and continued after the retreat of the glaciers. On this hypothesis the internal stratification of the moraines, the terraces on their inner sides, and the stranded boulders would be explained.

It was not till after this paper was read before the Society that I found that Mr. Gilbert had treated the subject of the correlation of glaciers and the Pleistocene lakes of the great basin very fully. On page 314 of his monograph (VI) Mr. Gilbert says:

"With one voice these four localities tell us that Mono Lake occupied its maximum level after the glaciers of the

Sierra had retreated from their most advanced position; but their testimony goes no farther. The narrow range of levels common to the two may have been occupied first by ice and afterward by the water, or it may have been occupied by both together. We can only say that the ice was first to retreat.

"Combining this result with that afforded by the moraines of the Bonneville basin, we conclude that the epoch of greatest glaciers fell within the second period of lake expansion, but did not coincide with the epoch of greatest water supply. It occurred somewhat earlier. If the two sets of phenomena were consequent upon the same series of climatic changes, then the lacustral changes lagged behind the glacial.

"That such a lagging admits of plausible explanation may readily be shown. The nevé and glaciers of the Mono district occupied a portion of the catchment basin of the lake. The precipitation which they accumulated during their growth was subtracted from the precipitation tributary to the lake, and the same was afterward returned to the lake when they were finally melted. Their mass of ice may therefore be regarded as a portion of the water supply of the lake, arrested in its progress. When the climatic conditions were favorable for the growth of lake and glaciers the growth of the glaciers antagonized and delayed the growth of the lake. When the climatic conditions favored the wasting of lake and glaciers the waste of the glaciers fed the lake and thus antagonized its depletion. The ascending and descending phases of the lake thus fell behind the corresponding phases of the glaciers, and the maxima and minima or turning points were correspondingly displaced.

"It is to be observed that this explanation is quite distinct from the theory, alluded to by Whitney (XVIII, page 185), that the Pleistocene lakes were the sequel of the Pleistocene glaciers, being created by their melting. Such a relation is quantitatively impossible. In the Mono basin, indeed, the mass of snow and ice upon the mountains may have been equal to the volume of water in the valley, but in the Lahontan and Bonneville basins it was far too small."

Faulting in the Lake Beds.

Besides the local faulting at Bennett's mine previously referred to, and which would be expected with any not thoroughly consolidated material on a steep slope, there is evidence of a line of faulting on the east side of Mohawk Valley.

The lake beds on the east side of the Feather River opposite Wash Post Office are plainly faulted. A very evident fault exists in the lake beds on the south bank of the river about one mile up-stream from Wash Post Office. About one-fourth mile still further east, at the locality where I obtained the fossil leaves, a fissure was formed in the tufa and breccia beds overlying the fossiliferous series at the time of an earthquake shock some years ago (about 1876).

This fissure was about two feet wide, and at the time warm air came out of it. The locality was formerly the resort of numerous rattlesnakes, attracted, no doubt, by the warmth. At the time of my visit, in 1889, slightly warm, moist air still issued from holes near the former fissure. A little east of the fissure is a warm sulphur spring. Near this is another spring which, according to Abel Jackson, who lived here at the time, was so warm that at the time of the earthquake the hands could not be held in the water.

The lake beds are flexed just east of the springs at the Sulphur Spring House, showing disturbance. The springs have now a uniform temperature of about 75° as tested in 1890.

Artesian wells sunk along the west side of Sierra Valley in some cases strike flows of hot water. The land slides noted in connection with the river gravel by Cedar Creek may be connected with faulting.

Relation of the Mohawk Valley Fault to the Structure of the Sierra Nevada.

The different localities above mentioned, together with the hot artesian wells in Sierra Valley, are approximately in line, which coincides very well with the general line of

faulting which Mr. J. S. Diller (III) has laid down as having formed the east escarpment of a huge orographic block. This block as outlined constitutes the main mass of the Sierra Nevada. Mr. Diller presumably bases his general scheme of faulting upon the previous work of Professor Le Conte and Mr. Gilbert, to whose papers he refers. This main escarpment forms the steep east slope of the Sierra Nevada, and is best seen west of Lakes Owen and Mono. For the extension of this great line of faulting which seems well substantiated by all geologists who have visited the above places, to the northward through Mohawk and American Valleys, we are, I think, indebted alone to Mr. Diller. My own observations substantiate the hypothesis of Mr. Diller so far as they relate to the existence of a line of faulting in Mohawk Valley. The existence of the hot springs seems to point to a fissure of some depth.

Mr. Diller establishes, in the publication just referred to, two other lines of faulting to the east of the main fracture. (See also IV.) The smaller of these, which is intermediate in position between the other two, all three being approximately parallel, extends along Little Grizzly Creek northwesterly to near Taylorville, in Indian Valley. The Grizzly Mountains lie between it and the main fracture to the west, and constitute another smaller orographic block. The other line of faulting is west of Honey Lake, the escarpment being best seen on the east side of Thompson Peak. The region between the Little Grizzly Creek fault and the fault west of Honey Lake constitutes Mr. Diller's third and most eastern block of the Sierra Nevada.

In Figure 1 these three lines of faulting are shown by black lines. Between Mohawk Valley and Mono Lake Valley the line of the main fault is indicated only by a dotted line, since positive evidence of faulting in this part of the Sierra Nevada has not, so far as I know, thus far been presented.

To well understand the basis for Mr. Diller's division of the Sierras into orographic blocks it will be necessary to take a brief review of the papers of Professor Le Conte and Mr. Gilbert, giving their important conclusions only.

In 1872, in his paper on the "Formation of the Great Features of the Earth's Surface" (VIII, page 355), Professor Le Conte says:

"I think, therefore, I am justified in asserting that the phenomena of plication and slaty cleavage demonstrate a crushing together horizontally and an upswelling of the whole mass of sediments, and that slaty cleavage demonstrates in addition that the upswelling produced by this cause alone is sufficient to account for the elevation of the greatest mountain chains."

On page 463 of the same article he further says:

"Mountain chains are formed by the mashing together and the upswelling of sea bottoms where immense thicknesses of sediments have accumulated, and, as the greatest accumulations usually take place off the shores of continents, mountains are usually formed by the uppressing of marginal sea bottoms. We will make this plainer by some illustrations taken from the history of mountain chains in North America.

* * * * * * *

"During the whole Triassic and Jurassic periods the region now occupied by the Sierras was a marginal sea bottom, receiving abundant sediment from a continental mass to the east. At the end of the Jurassic, this line of enormously thick, off-shore deposits yielded to the horizontal thrust and and the sediments were crushed together and swelled upward into the Sierra range. All the ridges, peaks, and cañons—all that constitutes the grand scenery of these mountains—has been the result of an almost inconceivable subsequent erosion."

In 1874 Professor Le Conte writes (IX, page 180):

"The *Sierra range* was first formed at the *end of the Jurassic* by mashing together and up-swelling only, while its subsequent slight increase *at the end of the Tertiary* was attended with great fissure-eruptions."

In 1878, in his article on the "Structure and Origin of Mountains," (XIX, pages 100–101), Professor Le Conte says:

"The Sierra Nevada may be taken as a typical example, both in form and in structure, of a monogenetic upheaval, or what I have called a range. * * * So simple appears the structure of this mountain that we might imagine that it consists of only one grand fold, eroded along its crest until the granite is exposed. * * * But this is probably not so, because forty miles of slates and schists outcropping at high angle would give an incredible thickness of sediments if we regard them as a single unrepeated series. It is probable, therefore, that these flanking slates really consist of several closely appressed folds, afterward deeply eroded so as to simulate a single series. * * *

"Again, the Sierra range is an admirable example of a fold passing gradually into a fault. In the northern portion of Lake Tahoe the slates occupy a broad area on *both slopes*, though largely covered on the eastern slope by volcanic ejections. The two slopes are more equal, and the height of the crest is moderate—only about 9,000 to 10,000 feet. The great wave [referring to the largest supposed fold forming the crest of the range] *is more normal.*

"In the middle portion, about Lake Mono, the eastern slate area is far narrower, the two slopes more unequal, and the crest higher, viz., 13,000 feet. The great wave *is ready to break.* In the southern portion, about Lake Owen, the eastern slope is still more abrupt, the eastern slates have entirely disappeared, granite alone forming the summit and the whole eastern wall, and the crest here reaches its highest point, near 15,000 feet. The great wave has *at last broken with the formation of a prodigious fault.* Remembering that the escarpment is here 10,000 to 11,000 feet, and that the whole thickness of the slates has been removed by erosion from its summit, and that their eastern continuation lies buried beneath the soils of the plains below, we cannot estimate this slip as less than 15,000 feet. It is probably much

more. It is almost certain that it was a slight readjustment of this slip which caused the Inyo earthquake of March, 1872.

* * * * * * *

"Marginal sea-bottom sediments are thickest near shore, and thin out very gradually seaward. Such sediments, therefore, even before yielding, form a lenticular mass, with the thickest part near the shore edge, and therefore asymmetric. Now, this already thickest part is precisely the line of greatest yielding and therefore of greatest upswelling, and thus the mountain wave becomes very asymmetric, with its steeper slope landward. Finally, the already asymmetric mountain is pushed over against the stiffened land crust, making a still steeper slope, which may even break on that side.

"Now, the Sierra is again an admirable illustration of this law. The oldest portion of the western half of the American continent is probably the basin region, especially its southern portion, running down into Mexico. During much of the Paleozoic and all the Mesozoic times until the end of the Jurassic this was a continental mass with its western shore near the eastern margin of the Sierra region. The Sierra region, as I have elsewhere shown, was then a marginal sea bottom, receiving sediments from the basin-region continent, until an enormous thickness had accumulated. When these thick sediments began to yield from the aqueo-igneous softening of their floor they would first swell up asymmetrically, and then be pushed over against the stiffened Basin region land crust, forming a steep slope, or even a fault and escarpment, on that side."

Professor Le Conte, in the same paper, ascribes a similar origin to the Wahsatch Mountains, which he regards as made up of sediments, on the eastern shore of the basin-region land mass, while their steep western and landward escarpment was formed in the same way that the steep eastern and landward escarpment of the Sierra Nevada was formed.

In 1880 Professor Le Conte wrote an important article on

the "Old River Beds of California" (XII). His conclusions in brief are that the enormous deposits of coarse sediments (the auriferous gravels) were caused by overloaded waters, which resulted from the melting of snow and ice, from the heat of the approaching interior lava which soon after was erupted, completely filling up the old river beds and causing their streams to seek new channels.

Glacial conditions are presumed to have commenced before the lava flows and to have reached their maximum after the lava flows. It is thought probable that the gradual elevation and the attendant glacial conditions commenced and advanced until the former culminated in the fracture and outflow of lava. He considers that there is a certain definite relation between slope and the amount of detritus which determines the depth of cañons.

If this relation be disturbed by increase of slope the stream will strive to re-establish it. Thus it has been with the great cañons of the plateau region, and thus it must have been with the cañons of the Sierra Nevada. Professor Le Conte says:

"It is difficult to imagine that the Tertiary river channels should have remained so shallow after the erosion of the whole Cretaceous and Tertiary times if the general Sierra slope were as high *then* as it is *now*, viz., 100 to 200 feet per mile. * * *

"The elevation which I suppose took place in the Sierra range at the time of the lava flow was evidently of a gentle kind, unaccompanied with crumblings and dislocations of the strata, and therefore undetectable except by the work of cañon cutting."

In reviewing Whitney's "Climatic Changes" (XVIII), in 1883, Mr. Gilbert (V, page 194) writes:

"If the inclination of the western flank of the Sierra was exceedingly gentle in Pliocene time, it would be natural for its streams to form deposits on the lower slopes; and if afterward an elevation occurred, increasing this inclination, the

habit of the streams would be reversed, and the cañons we see would result. That such a change in inclination has taken place is rendered probable by other considerations. In the first place, the western face, which is far broader than the eastern, is, as described by Whitney and others, an inclined plane, interrupted only by the narrow cañons of the modern streams. Its plateau character is not given by a continuous stratum of hard rock parallel to the general surface, but has been produced by the uniform erosion of a system of plicated strata. Such uniform erosion could only have been accomplished by streams flowing at a low angle. Second, the eastern boundary of the range or plateau is a line of faulting; and the orographic movement producing the range consisted of a displacement along this fault line, and a consequent inclination of a plateau-like mass to the westward."

In 1886 Professor Le Conte wrote a paper on the "Post-Tertiary Elevation of the Sierra Nevada" (XIII). On page 173 he says:

"The old river beds were probably established at the beginning of the Cretaceous, when the Sierra range was born from the sea and were being cut and shaped throughout the whole Cretaceous and Tertiary. By the end of that time * * * the rivers seem to have reached their base level and had ceased to deepen their channels, but rain erosion still continued to widen the valleys and cut down the divides. The river system had therefore assumed the form characteristic of old topography. Then came the lava flood, displacing the rivers, and the contemporaneous elevation changing the base level and enormously increasing the erosive power of the rivers. These, therefore, without loss of time, commenced cutting anew, and in comparatively short time have cut far lower than before. * * * It is impossible to explain this except by supposing a great rise, probably several thousands of feet, with increased slope of the range at the end of the Tertiary."

Professor Le Conte, on the evidence of Gilbert, Howell, and Russell, considers the fault scarps of the great basin to be due to *normal* faulting, which he considers due to *gravitative settling*. He says:

"It is certain that the great normal faults which characterize the basin region, among which must be counted the eastern Sierra fault and the western Wahsatch fault, were produced in this way long after the orogenic crumpling had ceased."

Professor Le Conte has still further elaborated methods of faulting in a paper "On the Origin of Normal Faults," published in 1889 (XIV). This may be taken as representing his present views.

Professor Le Conte assumes the earth to have a solid nucleus surrounded by a liquid layer on which the crust floats. He says:

"At the end of the Tertiary the whole region from the Wahsatch to the Sierra, inclusive, was lifted by intumescent lava into a great arch, the abutments of which were the Sierra on the one side and the Wahsatch on the other. * * *

"The arch broke down and the broken parts readjusted themselves by gravity into the ridges and valleys of the basin region, leaving the raw faces of the abutments overlooking the basin and toward one another. It must not be supposed, however, that this took place at once, but *gradually*, the lifting, the breaking down; and the re-adjustment going on *pari passu*."

"The Sierra Nevada is a great crust-block heaved and slipped on the eastern side, forming there a great fault of 15,000 to 20,000 feet vertical displacement, and this took place at the end of the Tertiary, accompanied by floods of lava."

It will be observed that Le Conte's views have undergone a marked change since his first articles were published. Supposing his assumption of a liquid substratum to be cor-

rect, his explanation of the formation of the basin ranges by gravitative settling finds confirmation in a paper by William Hopkins, in 1842 (VII), who demonstrated that a series of wedge-shaped blocks, formed by a system of normal faults cutting a given area of crust resting on a molten magma, would be differentially displaced, and that the blocks with the base of the wedge downward would be elevated relatively, and those with the apex of the wedge downward would settle. The relatively elevated blocks would form a system of flat-topped ridges with steep sides, the intervening blocks forming the floor of valleys.

This would not, however, account for the monoclinal ridges, which Professor Le Conte supposes to have been rhomboidal blocks, the overhanging side of which would tip, heaving up the other side.

It will be seen from Le Conte's earlier writings that he considered the Sierra to have attained nearly its present elevation at the time of its upheaval, and that at about that time a fault was formed west of Owen's Lake, which ran into a fold at about Lake Mono; also that the elevation of the range at the close of the Tertiary was a very slight affair.

He now evidently considers the range to have attained its present elevation by a considerable elevation at the close of the Tertiary, with the formation of a line of normal faulting along the base of the steep eastern scarp of the range.

We will here assume Mr. Diller's extension of this line of faulting through Mohawk and American Valleys to be correct. It will follow that the amount of faulting in recent times has not been great. Since the highest lake deposits occur on both sides of the line of fracture at an approximate elevation of 5,000 feet, it is evident that the amount of faulting since the existence of the highest stage of the lake must be measured in tens and not hundreds of feet.

On the supposition that the Pliocene beds containing the fossil leaves and the Mohawk Post Office beds are approximately of the same strata, these also being on opposite sides of the line of fracture and nearly of the same elevation, the

main faulting must have occurred before the existence of the so-called Pliocene lake, which, on the grounds before given, may be supposed to have existed.

Professor Le Conte studied the main fault scarp where it is at its maximum—that is, from Lake Mono south—but, so far as I know, has given no proof of so great a displacement as he indicates. The Sierra Nevada is thought to have been reduced to a base level of erosion during Tertiary time, and to have had an elevation not much, if any, greater than that of the great basin at the time of the displacement along Lake Mono and Owen's Lake. But while there is evidence of the river channels having had a very moderate grade during Tertiary time in the more northern part of the Sierra, so far as I know no evidence has been adduced to show that the Sierra Nevada did not constitute a mountain range during all of Tertiary time in the region where it is now highest, viz., to the west of Owen's Lake. No extensive gravel deposits, showing ancient rivers flowing at a moderate grade, have, to my knowledge, been found there, and it remains for the future geological explorer in that region to get evidence that may decide the question.

The general topography of the country indicates that the amount of displacement along the main fault scarp is much less in the region to the north of Lake Tahoe than from there south. Bearing on this point are some facts which I will now present. Referring again to Mr. Diller's orographic blocks as set forth in Bull. No. 33, U. S. G. S., there is evidence of an old river channel that originated as far south, at least, as Haskell Peak, which is south of Mohawk Valley, and flowed in a course a little west of north across all three of these blocks. If future investigations substantiate the course of this river as above it can be certainly shown that a differential elevation or subsidence of the land on opposite sides of the fault line of the Mohawk Valley of perhaps a thousand feet has taken place, but it will be equally certain that this displacement took place previous to the deposit of the Mohawk lake beds, even the oldest, and after the deposit

of the river gravels which now give evidence of the former existence of the river above mentioned. It could be also shown that the amount of faulting between the middle block, having its eastern escarpment along Little Grizzly Creek, and the eastern block, with its escarpment east of Thompson Peak, has been comparatively slight at the place where the river crossed the fault line.

The highest gravel area observed which is ascribed to the ancient river lies about one mile north of Haskell Peak at an elevation of 7,000 feet. The most northern area observed lies to the east of Little Grizzly Creek and north of the fortieth parallel at an elevation of about 5,800 feet. The gravel deposits of this old river are well exposed by hydraulic washings at several points, particularly at the Cascade gravel mine. The river probably existed in Eocene and Miocene times.

Mr. Diller informs me that he has traced the same channel still further north, and that he believes the river to have had a northerly course. During a subsequent season I hope to get positive evidence as to the course of this ancient river and its bearing on the question of faulting.

Professor Whitney believes the Sierra Nevada to have had substantially the same elevation in Tertiary times as now. (XVII, page 342.)

He accounts for the large accumulations of auriferous gravels in Tertiary times by supposing the precipitation, and consequently the volume, of water in the rivers to have been far greater at that time, and thinks that the present narrow and deep cañons were cut by streams constantly diminishing in volume.

In an excellent paper on "The Ancient River Beds of the Forest Hill Divide" (II, page 435) Mr. R. E. Browne gives the results of his investigations of certain channels in Placer county, California, which have been pretty thoroughly exposed by mining operations. He has been able to show that there are several channels of different ages, and has been able to map with absolute certainty portions of the courses

of these ancient streams. One very remarkable thing noted is the finding of fossil trees standing upright on the banks of one of these channels, having been overwhelmed by a mud flow of lava, such as many of the flows of breccia and tufa undoubtedly were, without being displaced.

On page 445 Mr. Browne says:

"If Professor Le Conte's view is correct, and the bearing of the axis of upheaval is north and south and the tilt to the west, one should expect to find in following the sinuous course of the tilted channel, first, the original grade maintained wherever the course is north or south; second, a greatly increased grade wherever the course is west; third, little or no grade wherever the course is east, * * * more data are wanted to settle the question of tilting. However, it may be said that the evidence, as far as it goes, is against any considerable increase in the slope of the Sierra flank—decidedly against an increase large enough to account *per se* for the two-thousand-feet-deeper cutting of the modern river."

The most decisive grade would be an easterly one. Unfortunately, none of these channels appear to have such a course, even for a few miles.

The last important paper is by Mr. Becker, "The Structure of a portion of the Sierra Nevada" (I). Mr. Becker accounts for the late elevation of the Sierra Nevada by means of distributed faults, of which he has found evidence during the past season. His explanation of how this occurred is somewhat elaborate, and the reader is referred to the original.

Résumé.

Mohawk Valley is the bed of a Pleistocene lake caused by the damming up of the cañon of the Feather River by a flow of andesitic lava.

Glaciers existed contemporaneously with the lake.

A line of recent faulting extends across the lake beds in a northwesterly direction. This line of faulting appears to

coincide with the east fault scarp of the Sierra Nevada as outlined by Le Conte and Gilbert and extended by Diller.

The amount of faulting since the deposit of the lake beds is to be measured in tens and not hundreds of feet.

If the course of an ancient river as described be later substantiated, the amount of faulting since perhaps Eocene times may be approximately measured.

The literature bearing on the elevation of the Sierra is briefly reviewed. Gilbert, Le Conte, Diller, and Russell regard the Sierra Nevada as being a tilted block of late origin, while Whitney, Becker, and Ross E. Browne believe the range to have had nearly its present elevation since the post-Mariposa upheaval.

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